HYCOM Consortium for Data-assimilative Ocean Modeling

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Document Number: N0001402WX20651
http://hycom.rsmas.miami.edu

LONG-TERM GOALS

Make HYCOM (HYbrid Coordinate Ocean Model) a state of the art community ocean model with data assimilation capability that can (1) be used in a wide range of ocean-related research, (2) be used in a next generation eddy-resolving global ocean prediction system and (3) be coupled to a variety of other models, including littoral, atmospheric, ice and bio-chemical.

OBJECTIVES

Collaborative 5-year (FY00-04) National Ocean Partnership Program (NOPP) project on the development and evaluation of HYCOM, a scalable and data-assimilative generalized (hybrid isopycnal/terrain-following (σ)/z) coordinate ocean model. Work with collaborators Eric Chassignet (overall project lead PI) and his group at the University of Miami, Rainer Bleck (Los Alamos National Laboratory), Ole Martin Smedstad (Planning Systems, Inc.), Carlisle Thacker (NOAA/Atlantic Oceanographic and Meteorological Laboratory) and Remy Baraille (SHOM). Apply HYCOM to two model domains, an eddy-resolving Atlantic domain (with ~7 km resolution at mid latitudes) and a coarser resolution global domain.

APPROACH

This includes many aspects of the ocean modeling that will be performed by or in collaboration with consortium partners and partnering projects (five at NRL in FY02). The data assimilation components are covered in other HYCOM related ONR reports.

1. Ocean model design: HYCOM is a generalized (hybrid isopycnal/σ/z) coordinate ocean model. It is isopycnal in the open stratified ocean, but reverts to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates near the surface in the mixed layer. This generalized vertical coordinate approach is dynamic in space and time via the layered continuity equation, which allows a dynamical transition between the coordinate types. Like MICOM, HYCOM allows isopycnals intersecting sloping topography by allowing zero thickness layers. HYCOM was developed from MICOM using the theoretical foundation for implementing a hybrid coordinate system set forth in Bleck and Boudra (1981), Bleck and Benjamin (1993), Bleck (2002) and Halliwell (2002).

2. Model development: HYCOM development is a close collaboration between Los Alamos (Rainer Bleck), NRL (Alan Wallcraft) and the University of Miami (George Halliwell), where the person in parenthesis is the lead performer in each group. Alan Wallcraft is in charge of developing and

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **HYCOM Consortium for Data-assimilative Ocean Modeling**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory Code 7304,,Stennis Space Center,,MS, 39529**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Make HYCOM (HYbrid Coordinate Ocean Model) a state of the art community ocean model with data assimilation capability that can (1) be used in a wide range of ocean-related research, (2) be used in a next generation eddy-resolving global ocean prediction system and (3) be coupled to a variety of other models, including littoral, atmospheric, ice and bio-chemical.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

maintaining the standard version of the model, one that is scalable/portable and can run on the latest computer architectures. Part of this work will be performed under a partnering Common HPC Software Support Initiative (CHSSI) project. HYCOM will be maintained as a single source code with the maximum feasible backward compatibility. Salient issues include the mixed layer and diapycnal mixing, the hybrid coordinate generator, developing a portable and scalable computer code, the capability to run HYCOM in MICOM-mode, the ability to initialize HYCOM from MICOM-mode or a true MICOM simulation, and diagnostic/visualization capabilities. A grid nesting capability is under development in a collaboration between U. Miami and a partnering project at NRL, the 6.2 Global HYCOM and Advanced Data Assimilation project sponsored by ONR (see separate report).

3. Ocean modeling applications: HYCOM will be applied to the Atlantic Ocean (28°S-70°N) in a close collaboration with Eric Chassignet's group and the global domain in collaboration with Rainer Bleck and Eric Chassignet. HYCOM has been tested on a 1/3° Atlantic model grid consistent with the DYNAMO Experiment before going to high resolution. The HYCOM results will be compared to simulations run using MICOM (Chassignet and Garraffo, 2001). The high resolution grid is .08° cos θ in latitude (θ) by .08° in longitude or ~7 km resolution for each variable at mid-latitudes. The high resolution Atlantic modeling will be performed mainly using a large grant of computer time provided by an FY02-04 DoD High Performance Computing (HPC) Challenge project with Eric Chassignet as the lead PI. NRL participation in the global modeling will begin in FY02 with .72° equatorial resolution. Later it will be increased to .24° and in FY04 to .08° in collaboration with partnering projects. Atmospheric forcing (wind and thermal) will be used from both the European Centre for Medium Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP). A wide range of data sets are available for model evaluation (Chassignet et al., 2000; Hurlburt and Hogan, 2000) and these papers discuss a wide range of climatological model-data comparisons. In addition, we have long time series of transports through the Florida Straits, sea level at tide gauges, and SST and subsurface temperature from moored buoys; also altimetric sea surface height (SSH) and IR SSTs from satellites, PALACE float and BT data and data from research field programs.

WORK COMPLETED

Two meetings of the HYCOM/NOPP partnership were held (Nov. 2001 and Feb 2002) to review progress and update the plans and milestones, technical issues, and responsibilities of the participants.

Model development and basic testing: Alan Wallcraft completed development of HYCOM 2.1 and it was released in Sept. 2002. This development included contributions from other NOPP/HYCOM consortium partners (see separate ONR reports), a 6.2 ONR Naval Ocean Modeling and Prediction (NOMP) project (HYCOM and advanced data data assimilation; see separate ONR report), and a 6.3 CHSSI project. A major aspect was development aimed at making the standard version of HYCOM ready for application as a fully global ocean model. Halos were added for MPI to automatically support periodic boundaries (6.3 CHSSI project). The capability to handle orthogonal curvilinear grids was added and used to create a bi-polar (PanAm) grid to cover the northern polar region. It matches the spherical grid convering the remainder of the global ocean at 47°N. Other salient additions to HYCOM 2.1 include support for nested-domain open boundaries (6.2 NOMP project), Mellor-Yamada 2.5 (Mellor and Yamada, 1982) and Price-Weller-Pinkel (Price et al., 1986) as new embedded mixed layer options (NOPP/HYCOM/U. Miami), support for multiple tracers, and NetCDF output files (6.3 CHSSI project).

For testing HYCOM 2.1 has been set up on a global domain with .72° equatorial resolution and 26 layers. It has been run for 5.5 years starting from the Levitus 1994 climatology (Levitus et al., 1994; Levitus and Boyer, 1994) with ECMWF high frequency climatological forcing. The high frequency climatological forcing was formed by adding the 6-hourly deviations from temporally interpolated monthly means for a specific year (Sept. 1994 – Sept. 1995) to a temporally interpolated monthly ECMWF climatology formed from the 1979-1993 ECWMF reanalysis. An energy loan sea ice model is used, a component scheduled for upgrade to the state-of-the-art Los Alamos/NCAR ice model during FY03.

Atlantic modeling (28°S-70°N): A 1/12° (~7 km mid-latitude resolution) eddy-resolving Atlantic Ocean model with data assimilation is a major goal of this NOPP project. During FY01 the Atlantic modeling was at 1/3° resolution with a ~2 mo run at 1/12° resolution. During FY02 an FY02-04 DoD HPC Challenge project was used to run 1/12° Atlantic HYCOM 8.4 years in a sequence of 3 experiments, 2+ years with monthly climatological ECWMF forcing, 3 years with 6-hourly high frequency monthly climatological forcing and July 1999 - July 2002 with 3 or 6 hourly hybrid Fleet Numerical Meteorology and Oceanography Center (FNMOC)/ECMWF forcing, where the FNMOC mean wind stress over 1990-2001 is replaced by the ECMWF reanalysis mean. The first of these HYCOM simulations was initialized from the best 1/12° MICOM Atlantic simulation and the other two from the preceding experiment. The first experiment was set up to emulate the MICOM experiment as closely as possible. Contributions to the meridional overturning from outside the model domain were included via relaxation to Levitus temperature, salinity and interface depth in 3° buffer zones along the northern and southern boundaries. The surface salinity forcing is a combination of evaporation-precipitation from COADS climatology and relaxation to the Levitus sea surface salinity climatology. Ice is included via a simple energy loan model. Since HYCOM can also be run in MICOM emulation mode, HYCOM was run for ~2 years in 1/12° Atlantic MICOM mode starting from the same MICOM state as the first of the 1/12° HYCOM Atlantic simulations. Ole Martin Smedstad used the July 1999-July 2002 Atlantic HYCOM simulation to initialize a data-assimilative 1/12° Atlantic HYCOM run (see separate NOPP/HYCOM/PSI ONR report).

RESULTS

The collaborative HYCOM effort including the HYCOM/NOPP consortium, partnering projects and the broader international community effort is working extremely well. It should be noted that advanced data-assimilative ocean modeling and prediction has become sufficiently complex that a multi-agency, multi-institutional consortium of expertise is essential. The National Ocean Partnership Program is proving an outstanding means to support such collaborations.

HYCOM 2.1 is scalable up to O(1000 cpus) via two levels of parallelization, either or both of which can be used, and it can run on computing platforms ranging from PCs to a variety of supercomputers with different parallel architectures. This was accomplished using a single source code for all machine types. HYCOM 2.1 supports a generalized (hybrid isopycnal/σ/z) vertical coordinate, orthogonal curvilinear "horizontal" coordinates, fully global ocean modeling using a bi-polar (PanAm) grid for the northern polar region, 4 mixed layer options, nested open boundaries, and multiple passive tracers.

The first 1/12° Atlantic HYCOM simulation was designed to emulate the best 1/12° Atlantic MICOM simulation which has a very realistic Gulf Stream pathway and slightly high for the meridional

overturning (21 Sv) (Chassignet and Garraffo, 2001). Aside from the hybrid vertical coordinate, the major deviations from MICOM are the mixed layer and the sub-mixed layer diapycnal mixing scheme. HYCOM uses KPP (Large et al., 1997) for both while MICOM has a Kraus-Turner (Kraus and Turner, 1967) type mixed layer and an explicit diapycnal mixing scheme (McDougall and Dewar, 1998). The high frequency wind forcing in the second HYCOM experiment is another significant deviation, since it tends to enhance mixed layer deepening. The first experiment needs to overlap the second one to better assess the impact of that, but the needed extension of first experiment is not yet completed. While analysis of the results is still preliminary, the first 1/12° HYCOM experiments are able to simulate the main features of the Atlantic Ocean circulation from the mesoscale to large scale circulation and water masses, some quite accurately, others with significant quantitative but not qualitative errors. Although other factors may be important as well, early analysis indicates the main quantitative errors are linked to increased vertical mixing in the southern buffer zone (25°S-28°S). This increases the strength of the Atlantic meridional overturning cell (MOC) (which was slightly high in MICOM) to unrealistically strong (~27 Sv) in HYCOM with high frequency forcing. Figure 1 indicates that the northern buffer zone does not contribute to excessive meridional overturning and that HYCOM simulates the overflow from the Denmark Strait very realistically, including the southward transport through the Denmark Strait and the transport increases downstream due to entrainment and contributions from other straits. Cross-sections (not shown) depict cold, fresh water from the Nordic Seas flowing southward through the Denmark Strait, sinking along isopycnals and entraining warmer, saltier Atlantic water.

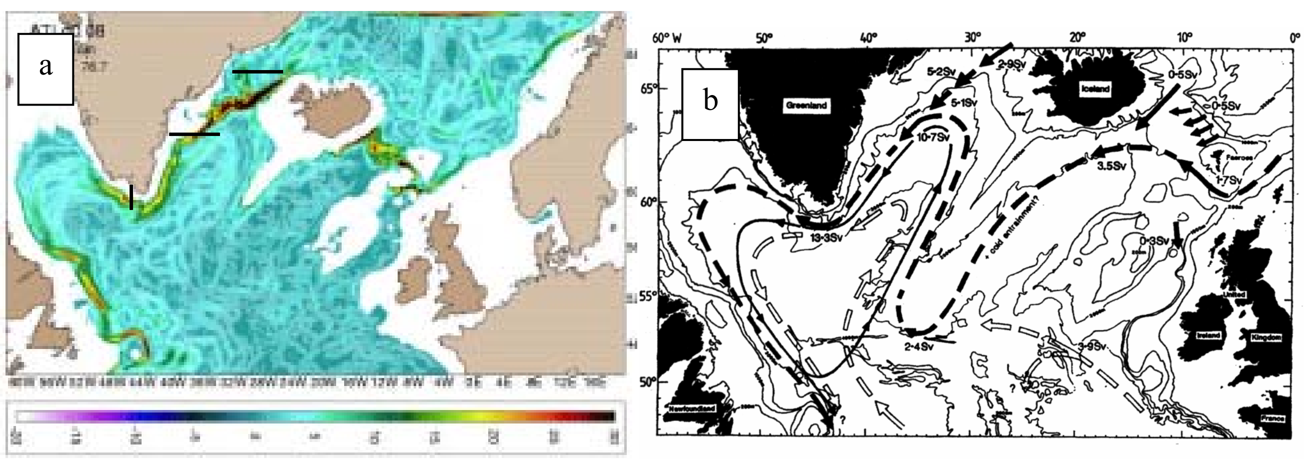

Figure 1. Southward deep transports in the Denmark Straits overflow region (a) simulated by 1/12° HYCOM vs. (b) observed using current meters (Dickson and Brown, 1994). Modelled (observed) transports (in Sv) across the sections marked by black bars on (a) are 4.1 (5.2) through the Denmark Strait, 9.4 (10.7) east of southern Greenland and 13.8 (13.3) at the southern tip of Greenland.

Accurate simulation of the Gulf Stream pathway between Cape Hatteras and the Grand Banks has been very challenging for ocean models. In the HYCOM simulations, the pathway parallels the observed and very accurate MICOM pathways and it lies within the one standard deviation pathway lines, but in a 2-year mean from the high frequency climatological simulation it is ~200 km too far south east of Cape Hatteras at 71°W. Using the dynamical mechanism of Thompson and Schmitz (1989), this is consistent with an excessively strong Deep Western Boundary Current associated with the strong MOC. Even though the MOC is too strong, the northward transport through the Florida Strait at 27°N

is ~8% too weak (27 Sv vs. 32 Sv observed). This is consistent with a vertical MOC structure that is too deep and a transport that is lower than observed above the ~740 m sill depth (Malloy and Hurley, 1970) of the Florida Strait, so that part of the flow is diverted east of the Bahamas (~19 Sv vs. 5 Sv observed by Lee et al. (1996)). Still the mean velocities and vertical and horizontal structure of the flow entering the Gulf of Mexico through the Yucatan Channel (not shown) demonstrates excellent agreement with a cross-section based on 1 year of extensive measurements by (Sheinbaum et al., 2002). The extension of the 1/12° HYCOM experiment with monthly climatological forcing will be completed and the results of these experiments will be analyzed more thoroughly during FY03. Although the southern buffer zone relaxation may need some tuning, the next planned modeling step is to change the reference depth for potential density from the surface to 2 km depth and to add thermobaricity, both capabilities which already exist in HYCOM and MICOM. This is known to improve the vertical structure of the MOC and to reduce the strength of the upper meridional overturning cell (Chassignet et al., 2002).

IMPACT/APPLICATIONS

HYCOM is designed to make optimal use of three types of vertical coordinate, isopycnal, σ and z-level. Isopycnals are the natural coordinate in stratified deep water, terrain-following (σ) coordinates in shallow water and z-levels in the mixed layer. The layered continuity equation allows a dynamical space and time varying transition between the three coordinate types. HYCOM also permits isopycnals intersecting sloping topography by allowing zero thickness layers. Therefore, it should allow accurate transition between deep and shallow water, historically a very difficult problem for ocean models. It also allows high vertical resolution where it is most needed, over the shelf and in the mixed layer. The isopycnal coordinate reduces the need for high vertical resolution in deep water. HYCOM is a new and promising design for next generation global and regional ocean prediction systems and it extends the range of application for ocean models in research. The NRL PI and Eric Chassignet (U. Miami) are members of the U.S. and International Steering Teams for the Global Ocean Data Assimilation Experiment (GODAE), a multinational project designed to help justify a permanent global ocean observing system by demonstrating useful near real-time ocean products.

TRANSITIONS

None.

RELATED PROJECTS

The HYCOM/NOPP consortium includes E.P. Chassignet (Coordinator), A. Mariano, G. Halliwell (U. Miami), T.M. Chin (JPL/U. Miami), R. Bleck (LANL), H. Hurlburt, A. Wallcraft, P. Hogan, R. Rhodes, and G. Jacobs (Naval Research Laboratory), O. M. Smedstad (Planning Systems, Inc.), W.C. Thacker (NOAA/AOML) and R. Baraille (SHOM). Partnering projects at NRL include an NRL 6.1 ONR JES DRI project, 6.1 LINKS, 6.1 Dynamics of Low Latitude Western Boundary Currents, 6.1 Thermodynamic and Topographic Forcing in Global Ocean Models, 6.2 Global HYCOM and Advanced Data Assimilation, 6.3 High Fidelity Simulation of Littoral Environments (CHSSI)) and 6.4 Altimeter Data Fusion Center (ADFC) Support. Additionally, the project receives grants of HPC time from the DoD High Performance Computing Modernization Office, including an HPC challenge grant entitled “Basin-scale ocean prediction with the Hybrid Coordinate Ocean Model”. The NRL PI is a member of the International and U.S. GODAE Steering Teams.

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